External electrodes on piezoceramic multilayer actuators

BACKGROUND OF THE INVENTION

The invention relates to the external electrodes on piezoceramic multilayer actuators and also to a method of producing them.

The structure and the production of actuators and their external electrodes is described comprehensively, inter alia, in DE 33 30 538 A1, DE 40 36 287 C2, US 5 281 885, US 4 845 339, US 5 406 164 and JP 07-226541 A.

A piezoceramic multilayer actuator is shown diagrammatically in Figure 1. Figure 2 shows, in an enlarged detail, the structure of the external electrode according to the prior art and Figure 3 shows a typical crack path after 10^6 loading cycles in the ceramic material under an external electrode according to the prior art. Piezoceramic multilayer actuators 1 are constructed as monoliths, that is to say they are composed of stacked thin layers 2 of piezoelectrically active material, for example lead zirconate titanate (PZT) with conductive internal electrodes 7 that are disposed in between and that are alternately routed to the actuator surface. Prior to sintering, as a so-called green film, the active material is provided with internal electrodes 7 by a screen-printing method, pressed to form a stack, pyrolysed and then sintered, which produces a monolithic multilayer actuator 1.

External electrodes 3, 4, 8 connect the internal electrodes 7. As a result, the internal electrodes 7 on a respective side of the actuator 1 are connected electrically in parallel and thus combined to form a group. The external electrodes 3, 4 are the connecting poles of the actuator. If an electrical voltage is applied to the connecting poles, it is transmitted in

parallel to all the internal electrodes 7 and induces an electric field in all the layers of the active material, which deforms mechanically as a result. The sum of all these mechanical deformations is available at the end faces of the actuator as usable expansion 6 and/or force.

The outer electrodes 3, 4, 8 on the piezoceramic multilayer actuators 1 are constructed as follows: a basic metallization 3 is applied to the stack of pressed thin layers 2 of the piezoelectrically active material in the region of the routed-out internal electrodes 10, for example by electroplating methods or screen printing of metal paste. Said THE basic metallization 3 is reinforced by a further layer 4 composed of a metallic material, for example by a structured metal sheet or a wire lattice. The reinforcing layer 4 is joined to the basic metallization 3, for example, by means of a solder layer 8. The electrical connecting wire 5 is soldered to the reinforcing layer 4.

External electrodes constructed in this way have a serious disadvantage. During operation, severe tensile stresses act on the insulating layer 11 that is situated underneath the basic metallization 3. Since said THE insulating region 11 forms a homogeneous unit together with the basic metallization 3 and the joining layer 8, as a rule a solder layer, said unit breaks down when the tensile strength of the weakest member is exceeded and cracks are formed. The cracks usually run from the brittle and low-tensile basic metallization 3 into the insulating region 11 and are trapped there by regions having high tensile stresses, preferably at the electrode tips 9 of the electrodes 12, which do not touch the basic metallization 3, or they start in the

regions of maximum tensile stress at the electrode tips 9 and extend in the direction of the basic metallization 3. These typical cracks 14 are shown in Figure 3.

The spreading of a crack 13 along an internal electrode 10 touching the basic metallization 3 is classed CLASSIFIED as not critical since such a crack path does not impair the function of the actuator. On the other hand, cracks 14 that extend in an uncontrolled manner through the insulating region 11 are very critical since they reduce the insulating distance and considerably increase the probability of actuator failure due to flashovers.

Solutions to the problem are described, for example, in Patent Applications DE 198 60 001 A1, DE 394 06 19 A1 and DE 196 05 214 A1. In the latter, it is proposed to provide the region between an electrode not touching the basic metallization and the basic metallization with a filling material of low tensile strength or a cavity. The important disadvantages of this procedure are to be perceived in the fact that the filling material has to be applied by means of an additional, complex method step and that the filling material inevitably adversely affects the properties of the actuator and, in the case of the introduction of cavities, the latter have to be closed again in a further method step prior to the application of the basic metallization.

Another solution to this problem is proposed in DE 199 28 178 A1. In this case, the monolithic structure is broken down into small subregions and reconstructed in an alternating manner with inactive, electrode-free regions. In this case, the maximum possible tensile stress is intended to remain below the value necessary for crack formation within an active region. The method

is difficult from a production-engineering standpoint and does not result in the necessary reduction in the stresses in the insulating region, with the result that a latent danger of cracks always continues to exist.

OBJECTS AND SUMMARY OF THE INVENTION

The object of the invention is to design the external electrodes on multilayer actuators in such a way that the causes of crack formation in the actuators are avoided as far as possible and that, if cracks occur, their path is controlled in such a way that it does not result in the destruction of the actuators.

The object is achieved, according to the invention, in that the basic metallization of the external electrode is no longer a continuous area, but is structured, the structuring being formed by discontinuities or recesses. Further advantageous embodiments of the invention are claimed in the dependent claims.

The structuring of the basic metallization in the outer electrode reduces, in totality, the rigidity of the composite comprising ceramic surface, basic metallization and joining layer, as a result of which preferred directions for the crack spreading are produced when cracks occur. The structuring has the effect that the mechanical reaction of the external electrode on the actuator and, consequently, also the crack initiation is reduced without endangering the adhesive strength of the external electrode and the reliable contacting of the internal electrodes.

However, as a result of the structuring of the basic metallization, areas must remain that are at least large enough for respective adjacent internal electrodes to be joined together by at least one area.

Furthermore, the discontinuity of the basic metallization in the external electrode produces, at the actuator surface, regions in which an interaction takes place between the joining layer that joins the reinforcing layer to the basic metallization, in particular in the case of a solder layer, and the internal electrodes routed outwards. As a result of the discontinuities in the structure of the basic metallization, metal from the solder may become alloyed to the internal electrodes when the reinforcing layer is soldered on. The consequence is that the insulating regions are weakened at these points, which produces preferred points for possible crack formations and the crack path. As a result of the control of soldering time and soldering temperature, the penetration effect can be adjusted so that, during the subsequent operation of the actuator, almost every internal electrode becomes a deflector for a developing crack. The stress in the microstructure of the insulating region is thereby reduced to a maximum extent, the cracks remain harmless and cracks can no longer be formed that extend through the ceramic material. No additional steps need to be formed in the manufacturing process. Because of the low process temperature during soldering, the ceramic material is not damaged.

In the case of multilayer actuators having the basic metallization structured according to the invention, cracks are therefore formed exclusively along the internal electrodes routed outwards and these are advantageously not critical because they do not impair the function of the actuator.

The invention is explained in greater detail by reference to exemplifying embodiments. In the drawings:

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 4 shows a basic metallization that has been produced by means of screen printing with a termination paste, having a structure according to the invention composed of individual dots,

Figure 5 shows a basic metallization having a structure according to the invention composed of individual lines,

Figure 6 shows a basic metallization with a lattice-type structure according to the invention, and

Figure 7 shows a basic metallization having a structure according to the invention that has been formed from a metallization printed over the entire area by mechanical removal.

DETAILED DESCRIPTION

The diagrammatic structure of the multilayer actuators used here corresponds to that shown in Figure 1. The external electrodes according to the invention differ from the external electrodes shown in Figures 2 and 3 in the structuring of the basic metallization.

The structuring, according to the invention, of the basic metallization was tested on five exemplifying embodiments. For this purpose, parent bodies of multilayer actuators were first produced according to Figure 1 and the basic metallization was applied to them in various patterns. The external electrodes of the actuators were then completed.

The parent bodies of the actuators are produced as described below: from a piezoceramic material that sinters at low temperature, for example SKN53 according

FIG 1 is a diagrammatical drawing of a prior art piezoceramic multilayer actuator.
FIG. 2 is an enlarged detail of an external electrode according to the prior art.
FIG. 3 shows a typical crack path after 10^6 loading cycles in the ceramic material under an external electrode according to the prior art.